Advanced Research

Opening New Frontiers in Power

Introduction

Program Areas

- Materials and Advanced Metallurgical Processes
- Coal Utilization Science
- Bioprocessing
- University Coal Research
- Historically Black Colleges and Universities/Other Minority Institutions
- International/Coal Technology Export
- Computational Energy Science

The challenge of providing the Nation with a secure energy supply and devising ways to use energy more efficiently and less harmfully is a fundamental scientific challenge.

The Advanced Research program serves as a bridge between basic research and the development of innovative systems capable of improving efficiency, and environmental performance while reducing costs of fossil energy systems, both for electric power and liquid fuels production. Advanced research provides the means by which advanced concepts are transformed into future working technologies for use in the U.S. and abroad. Improvement of the energy infrastructure — power plants, power transmission systems, fuel production and transportation systems, coproduction of higher value products (such as chemicals), environmental protection, and remediation efforts — is dependent on the products of advanced research.

The Advanced Research program provides two major products. The first is a set of crosscutting studies and assessment activities in environmental, technical, and economic analyses, coal technology export, and international program support. The second identifies and guides advanced research in new directions and provides a set of crosscutting fundamental and applied research programs focused on developing the technology base in the enabling science and technologies needed for the 21st century. These areas are critical to the successful development of both ultra-clean, very high efficiency coal-based power systems, and coal-based fuel systems with greatly reduced or zero emissions of carbon dioxide (CO_2). This second set of activities addresses the full spectrum of fossil the utilization research and development (R&D), technology transfer, outreach, and private sector partnerships.

Integral to achieving the goals of the Advanced Research program is expansion of the Focus Area for Computational Energy Science. Established at the National Energy Technology Laboratory (NETL), the Focus Area for Computational Energy Science will provide the computational technical support for innovative concepts, ideas, materials, components, and subsystems that will be the basis of success for the energy plants of the 21st century.

The Advanced Research program is directly related to other programs within Coal & Power Systems (C&PS). Advanced Research provides the key to developing innovative concepts for application in the commercial program areas by: (1) supporting the research necessary to graduate new technologies to the development stage; and (2) initiating research that is likely to lead to entirely new technology areas, and possibly to entirely new program areas.

It should be noted that often the processes and materials that advance one C&PS program may well have application in another with little or no modification. A major advantage of the Advanced Research program is its ability to see and foster applications of a given technology across a number of programs, and leverage scarce resources to accomplish common goals.

DRIVERS

The Advanced Research program supports Vision 21 and is an integral part of the Central Systems, Distributed Generation, and Carbon Sequestration programs. As such, the Advanced Research program is driven by many of the same market and environmental influences as other C&PS programs.

Utility deregulation, energy security, the growing global demand for energy, the aging fleet of U.S. coal-fired power plants, global climate change initiatives, and environmental compliance concerns all have implications for the long-term use of fossil fuels.

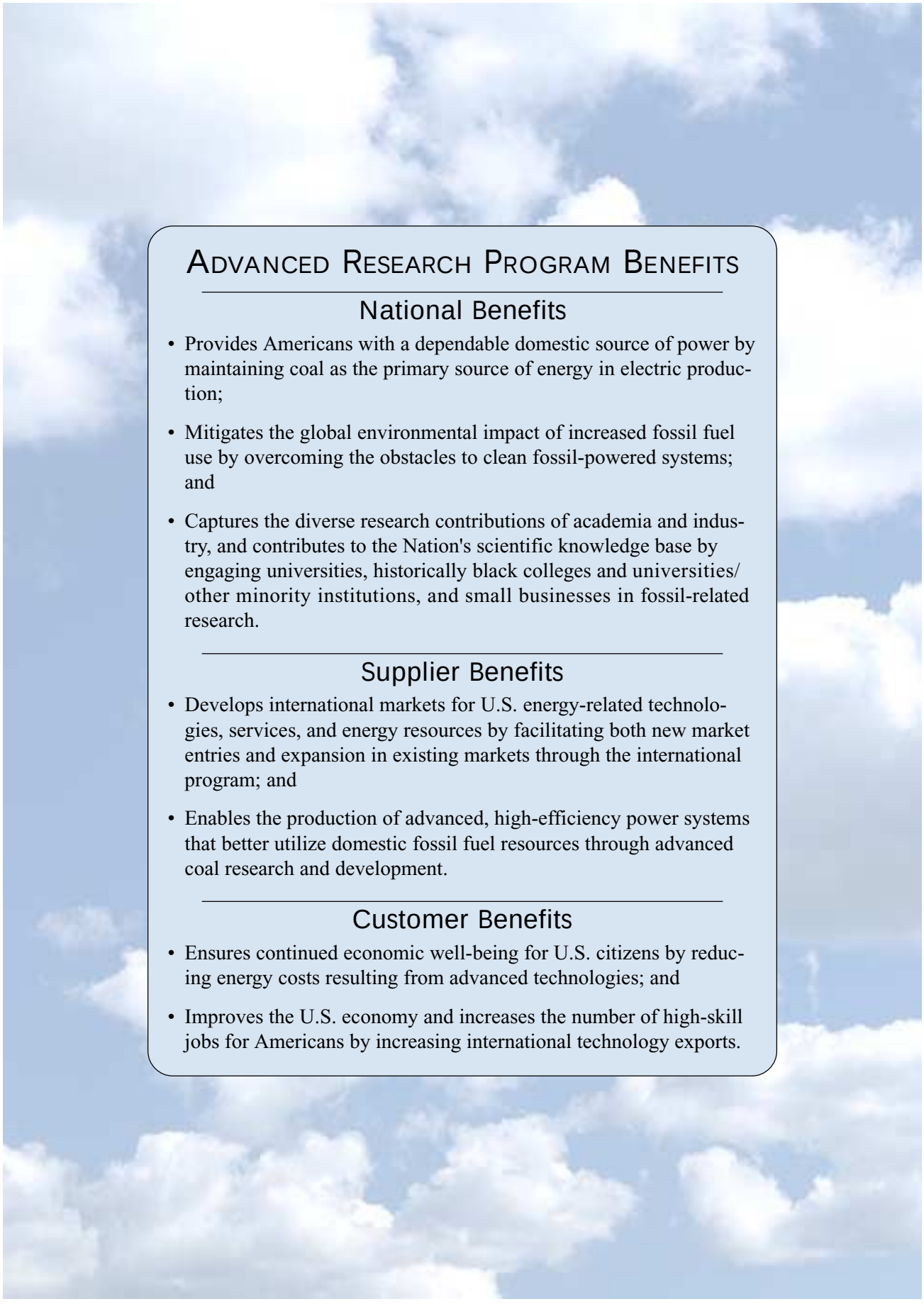
Link to Vision 21. The Vision 21 concept defines the activities of the Advanced Research program by setting priorities for the 21st century.

The research thrusts of the program include identifying a next generation of advanced fuel and power systems that can operate at greater efficiencies on coal and at an economic cost that is lower than for the present state-of-the-art, while emitting practically no pollutants and, with sequestration, having no net emissions of CO_2. The major goal of the Advanced Research program is to develop, by 2015, a series of advanced materials, subsystem technologies, and breakthrough process concepts that are essential to the success of Vision 21. To achieve these goals, an NETL Center of Excellence for Advanced Research is being developed. This center will allow applied research to be conducted now to produce a technology base from which the energy plants of the future will be designed, built, and operated.

In order to achieve the performance goals of Vision 21, a number of challenging R&D issues must be addressed by the Advanced Research program. Though not meant to be an exhaustive list of critical research needs to achieve Vision 21, these needs include:

- Low-cost oxygen separation technology;
- Advanced carbon products, such as nano-structural materials;
- High-temperature hydrogen separation technology;
- Heat exchanger materials capable of operating at combustion temperatures; and
- Approaches to effectively capture and sequester CO_2.

An artist's rendering of a Vision 21 plant



Advanced Research Program Benefits

National Benefits

- Provides Americans with a dependable domestic source of power by maintaining coal as the primary source of energy in electric production;
- Mitigates the global environmental impact of increased fossil fuel use by overcoming the obstacles to clean fossil-powered systems; and
- Captures the diverse research contributions of academia and industry, and contributes to the Nation's scientific knowledge base by engaging universities, historically black colleges and universities/ other minority institutions, and small businesses in fossil-related research.

Supplier Benefits

- Develops international markets for U.S. energy-related technologies, services, and energy resources by facilitating both new market entries and expansion in existing markets through the international program; and
- Enables the production of advanced, high-efficiency power systems that better utilize domestic fossil fuel resources through advanced coal research and development.

Customer Benefits

- Ensures continued economic well-being for U.S. citizens by reducing energy costs resulting from advanced technologies; and
- Improves the U.S. economy and increases the number of high-skill jobs for Americans by increasing international technology exports.

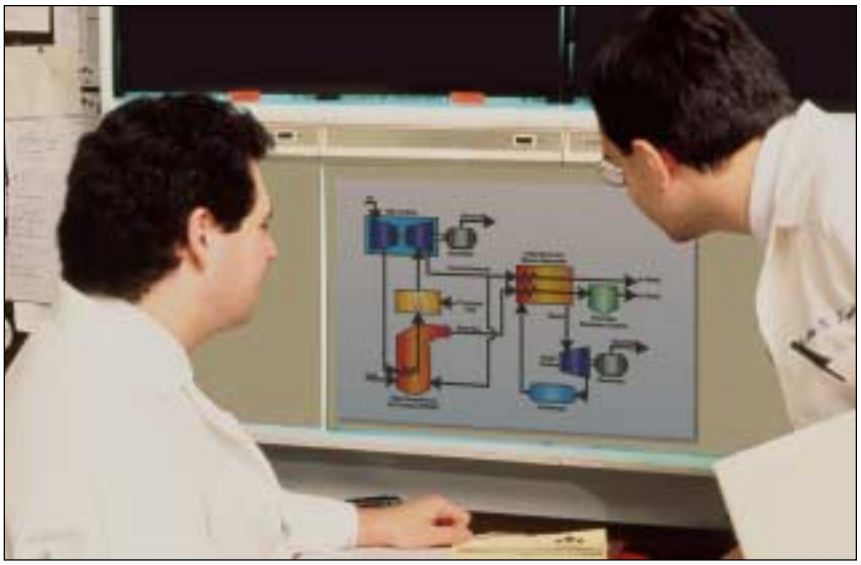
ACTIVITIES

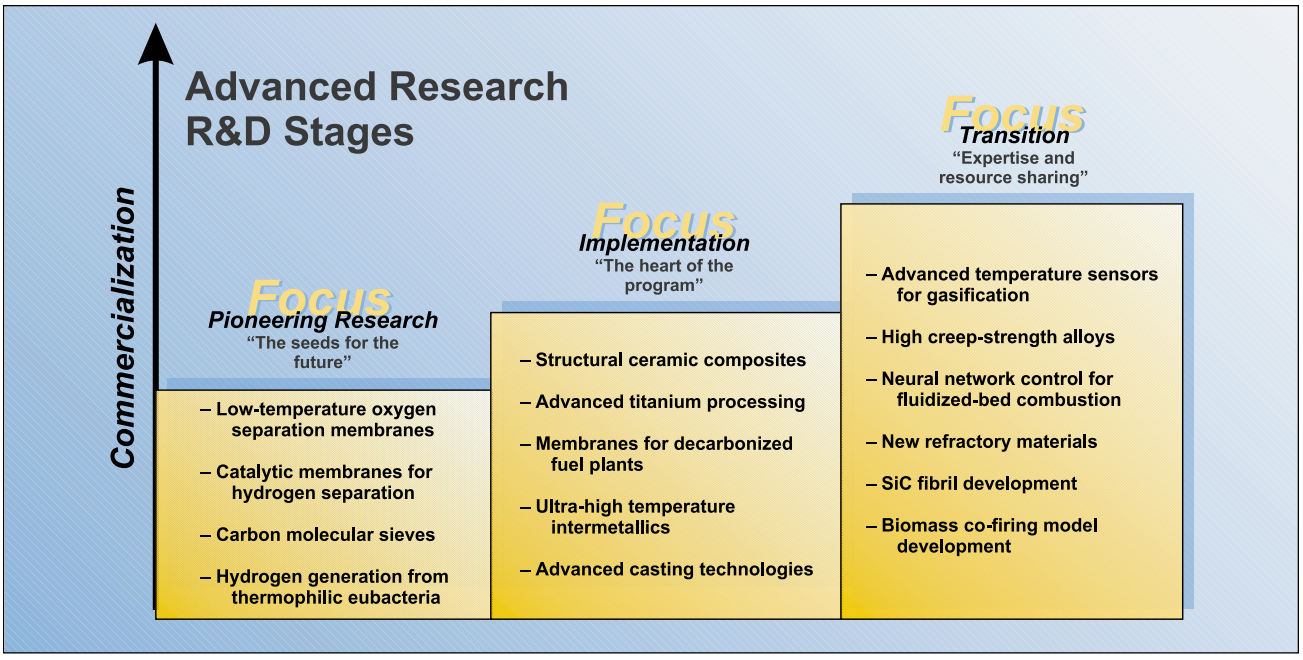
The Advanced Research program is charged with coordinating and directing research that will lead the technological developments of the C&PS program.

As such, the Advanced Research R&D portfolio does not lend itself to a traditional roadmap or timeline since nearly all Advanced Research R&D follows the same progression through three stages of development consisting of pioneering research, implementation, and transition. This cycle meets the Advanced Research program goal of sponsoring pioneering research (the seeds for the future); nurturing and implementing fundamental research (the heart of the program); and, with other C&PS programs, facilitating the transition of new technologies into practice (expertise and resource sharing).

Examples of ongoing research in the different stages can be found below. Individual program area research can be found in the program areas discussion to follow.

The nature of the Advanced Research program is that virtually all of the products are in a pre-emerging phase of product development. Additionally, because the program is by nature crosscutting in its activities, it allows for a more integrated approach to evaluation of potential development areas. As concepts are proven to have reasonable potential, they are graduated to the appropriate C&PS program to complete the emerging phase of development. As a corollary function, the Advanced Research program evaluates input from other programs and from potential stakeholders to assist in determining the direction of emerging research areas.





Drivers

- Climate change initiatives will likely require signigicant carbon reductions in the electrical generation and transportation sectors.
- Governments may enact new and, as yet, undefined environmental regulations that could require even further reductions in emissions from stationary and mobile sources.
- Coal not only faces environmental challenges, but faces competition from the other fossil fuels — oil and natural gas. With natural gas prices projected to be relatively stable through 2015, natural gas could be the fuel of choice of electric utilities and independent power producers to satisfy future electric demand.
- The existing stock of U.S. fossil-fueled power plants is growing older, and little new generating capacity is currently being added. After about 2010, this situation will result in the need for substantial new generating capacity over and above that required to meet the growing demand due to population and economic growth.
- With deregulation, the utility industry is consolidating and keeping older plants operating longer to remain economically competitive. The questions of how this will affect availability and reliability of electric supply, and the deployment of advanced technologies, will probably remain unanswered for some time.
- Demand for electricity overseas is expected to grow substantially over the next several years. This will create a huge market for new electrical generation capacity that is well matched to regional characteristics.
- U.S. dependence on imported oil and gas continues to grow. By 2015, imported oil is expected to amount to 61 7-6 percent of consumption, and imports of natural gas to 14 percent of consumption.

Objectives

- Overall, deliver the scientific understanding and technological innovations that are critical to the success of C&PS programs as well as the Office of Fossil Energy and Department of Energy missions.
- Leverage research opportunities through science partnerships and pursue international science collaborations.
- Generate fundamental knowledge and data to make significant improvements in power plant efficiency and environmental performance.
- Develop advanced materials and enabling technologies for Vision 21 power systems, with no negative impact on the environment.
- Promote strong relationships between the Department of Energy and the academic community through research activities directed toward advancements in advanced power systems.
- Support the Office of Fossil Energy in developing collaborative technical activities with international performers in the coal and advanced power system areas.

Strategies

- Develop advanced materials for both functional and structural requirements of Vision 21 energy plants.
- Develop high-gas-flux oxygen separation device based on ion-transport membranes.
- Conduct refractory materials research.
- Design, evaluate, and scale up processes for CO_2 mineral sequestration.
- Develop advanced concepts for NO_X control.
- Research evolution of contaminants and air toxics.
- Develop instrumentation sensors and controls for advanced energy plants.
- Identify oxygen resistant bacteria for denitrification of flue gases.
- Investigate biohydrogen generation from carbon-containing waste products.
- Develop and test biological CO_2 sequestration processes.
- Develop toxins to safely control zebra mussels.
- Provide increased opportunities to train the next generation of American fossil fuel scientists and engineering researchers.
- Promote strong relationships between the Department of Energy and the academic community.
- Create partnerships with utilities and organizations to advance U.S. interests in carbon management by promoting deployment of clean energy systems.

Performance Measures

- Complete development of novel activated carbon fiber filter material gas separation and storage. (2001)
- Complete exploratory development of use of low-cost inorganic membrane technology. (2001)
- Develop continuous casting process to produce reduced-cost titanium. (2001)
- Complete CO_2 mineral sequestration bench-scale testing.
- Complete models necessary to mitigate emissions caused by ash fouling and slagging. (2001)
- Complete model for coal char combustion. (2002)
- Complete small-scale model tests of enzymatic activities for coal beneficiation. (2003)
- Demonstrate production-scale biohydrogen generation using extremophiles. (2003)
- Provide between 20 and 25 grants annually to teams of university students and professors.
- Conduct studies and develop information to encourage and assist U.S. industry in deploying clean coal technology and cleaner energy systems globally. (2001–2005)
- Develop International Capacity Building initiative. (2001)
- Complete advanced modeling tools for sub-elements in turbines and fuel cells. (2003)

Materials and Advanced Metallurgical Processes

Advanced materials are vital to enhancing the cost and performance of fossil energy systems. Today, research is focused on developing high-temperature, corrosion-resistant structural ceramic composites and alloys, and materials that perform specific functions in hostile fossil fuel environments.

The goal is to develop construction materials including the associated processing and fabrication methods, and the functional materials necessary for coal fuels and advanced power generation systems. These systems include coal gasification, heat engines, combustion systems, and fuel cells. The activities included in this program area focus on developing a technology base in the synthesis, processing, life-cycle analysis, and performance characterization of advanced materials. Research and development is aimed at developing ceramics (composite structural ceramics, solid-state electrolytes, membranes, and ceramic filters), new alloys (intermetallics, filters, advanced austenitic and ferritic alloys, and coating and claddings), corrosion research, and technology development and transfer.

New materials are being developed under the Materials and Advanced Metallurgical Processes program area to address the special needs of Vision 21. The ceramic materials required for novel membrane applications (including low-cost oxygen separation and hydrogen separation) and special alloys for high-temperature heat exchangers are examples of products of this activity that are critical to the timely deployment of Vision 21 energy plants.

Partnering and cost-sharing with industry are central components of the program area. FE's overall materials research program area includes widespread participation from industrial partners, universities, not-for-profit agencies, as well as the Advanced Research Materials program at Oak Ridge National Laboratory and the Advanced Metallurgical Research program at Albany, Oregon, and related activities within the Office of Science and Technology at NETL.

The Materials and Advanced Metallurgical Processes program area places special emphasis on technology transfer, ensuring that the materials will be available for subsequent fossil commercial applications. This emphasis enhances U.S. technological competitiveness, not only in the fossil arena, but also in the materials industry in general and other technology application areas as well.

Coal Utilization Science

Creating efficient, economic, and environmentally acceptable advanced fossil energy systems requires new knowledge of the fundamental mechanisms and processes that influence and control these systems. The acquisition of this information — needed by developers, designers, manufacturers, and operators — is a primary objective of the Coal Utilization Science program area.

This program area supports research that develops technologies for clean, efficient power generation from coal and other fossil fuels. Its emphasis is on producing fundamental information on the underlying processes and mechanisms that form technological barriers, by performing experimental research and theoretical investigations. Novel processes that address environmental issues as well as power generation are included in the program area. The Coal Utilization Science program area contracts with businesses, universities, and government laboratories, often forming multi-laboratory, multi-disciplinary teams to address complex issues.

Strength Through Science

The following state-of-the-art virtual demonstration capabilities being performed by the Coal Utilization Science program area strengthen the scientific base of design and demonstration tools. These tools form the basis for the software necessary to design, evaluate, and optimize the performance of the next generation of fossil-fired power systems.

3-D Visualization. Consists of 3-D solid models, compatible with 2-D drawings allowing interactive virtual reality.

Information Systems. Involves development of a multi-modal (graphical, textual, alpha-numeric, video, etc.) data management system. This will allow one-step/one-time data entry, and guarantee data integrity.

Communication Systems. Allows for Internet collaboration between a geographically-separated work team.

Computer-Aided Drawing. Will provide engineering drawings (schematic diagrams, termination drawing, structural) to generate reports with total integrity using 3-D models.

Process Simulation. Integrates process optimization, economic valuation, component sizing, sensitivity analysis with visualization, CAD, and other components of the virtual demonstration.

Control Systems. Tightly coupled Vision 21 systems will require sophisticated transient control strategies for normal operation, load following, start up/shut down, and safety.

Mechanistic Modeling. Models are physics-based and include computational fluid dynamics (including single/multi-phase, heat transfer, chemical reactions, radiation), finite element structural simulation, material simulation, and event-based simulation.

Bioprocessing, UCR, and HBCU

Bioprocessing

This program area sponsors research into biology, biochemistry, microbiology, and bioengineering technologies. Program area goals focus on the bioprocesses capable of fostering innovative uses for coal by-products, developing alternative fuels, identifying biomass sources for potential value in burning or co-burning technologies, developing biological processes to sequester and/or recycle greenhouse gases, addressing environmental issues affecting the power industry, and biologically mitigating fossil fuel mining and utilization issues.

Enzyme research aims to improve the bioconversion of coal to fuels

Six historically black universities and other minority institutions will share nearly $1 million in federal funding this year for fossil energy projects ranging from oil reservoir characterization, to designs for low-emission burners, to pollution reduction from car engines

University Coal Research

The Office of Fossil Energy conducts an annual competition to select and fund the best coal science and technology research proposals from the Nation's academic institutions. Grants are provided by the University Coal Research program area to U.S. universities in order to support fundamental research and develop improved fossil energy technologies. Novel and innovative approaches are sought to solve national and global environmental and energy-related issues. This research sustains U.S. global preeminence in the areas of fossil fuel science and engineering, by supporting fossil energy research at our Nation's universities. The result is a developing and expanding knowledge base in disciplines relevant to fossil fuels.

Historically Black Colleges and Universities/Other Minority Institutions

This program area was established to provide a mechanism for cooperative research between historically black institutions and other minority institutions with U.S. industries and federal agencies. This program area strives to support the education of scientists and engineers, and sponsors research in support of FE's programs. The HBCU/OMI program area has emphasized improving the environmental compatibilities of advanced coal, oil, gas, and environmental technology concepts.

Innovative Concepts: 2000 University Coal Research Grants

Marking the 22nd year of a DOE program that combines student education with research, the University Coal Research program area recently awarded federal grants to 18 university research projects. Since its inception in 1979, approximately 1,385 students have participated, along with their teaching professors.

The wide range of research topics includes new ways to turn pollutants from coal into environmentally safe, commercially valuable products; innovative technologies that produce clean hydrogen for fuel cells; and novel approaches for preventing the release of greenhouse gases.

Seven of the 18 projects will focus on "innovative concepts," an area created in 1997 to stimulate novel technological breakthroughs. In this category, proposers are free to submit projects on any coal-related topic for one-year study grants. Beginning this year, innovative concepts projects will be eligible for a future second phase of competition. This year's recipient's include:

- **University of Cincinnati, Cincinnati, Ohio**, will develop a new ceramic membrane that can remove carbon dioxide, a greenhouse gas, from high-temperature coal gases.
- **Drexel University, Philadelphia, Pennsylvania**, will synthesize another type of membrane for separating carbon dioxide from power plant exhausts. This membrane will use a ceramic material with more uniform and ordered pores than other types of membranes, and a chemical called a "surfactant" that is expected to move the CO_2 through the membrane faster.
- **University of Kentucky, Lexington, Kentucky**, will test membranes based on microscopic carbon nanotubes for separating CO_2 from the gases of coal-based power plants.
- **Brown University, Providence, Rhode Island**, will examine the major operational problems in co-firing coal and biomass by partially combusting only a fraction of the fuel to limit CO_2 emissions.
- **Pennsylvania State University, University Park, Pennsylvania**, will investigate a novel approach for converting the CO_2 in a power plant's flue gas into industrially useful products.
- **University of Utah, Salt Lake City, Utah**, will use a 3-D computer model to study the effects of recycling CO_2 back into an oxygen-enriched coal combustor.
- **The State University of New York at Buffalo, Buffalo, New York**, will develop a computer-based method for designing the ideal way to capture the exhaust heat of a power plant and use it to generate additional electricity.

International/Coal Technology Export

Worldwide, the demand for power is increasing exponentially.

The global market for electric power systems by 2010 has been estimated at nearly $2.3 trillion, and over half of this investment will be for coal-fired units. At the same time, the energy sectors of many countries are undergoing major transformations. Increasingly stringent environmental regulations, growing international concerns over global climate change, and increased competition among fuels drive the need for advanced power technologies that deliver electricity efficiently, cleanly, and economically both in the U.S. and abroad.

The International program area within the Advanced Research program has four major strategies:

- *Provide leadership in international organizations.* FE holds leadership roles in several international organizations — the International Energy Agency, Latin America Energy Organization, Asia Pacific Economic Cooperation's Regional Energy Cooperation Working Group, United Nations Economic Commission for Europe Clean Coal Technology Initiative, and the World Energy Council.
- *Maximize export opportunities.* The United States is the world leader in the development of clean fossil-powered technologies. The International program area works to ensure that United States companies get a share of the global market for clean power systems, thereby securing jobs, driving economic growth for the U.S., and contributing to global environmental protection.
- *Establish effective partnerships.* Partnerships play an important role in overcoming barriers facing U.S. companies that pursue export opportunities. Such barriers include trade, finance, inadequate understanding of U.S. clean power systems, and unfair competitive trade practices. Through its partnerships, the program facilitates business solutions to remove these barriers.
- *Facilitate electricity transactions across international borders.* The International program area ensures reliability and open-access transmission through border systems. The program area authorizes exports of electricity, collects and analyzes information on international electricity trade, conducts country-specific studies on electric power systems and the construction of international transmission lines, and provides electric power regulatory assistance.

To ensure that U.S. companies get a share of the global market for clean fossil-powered systems, bilateral efforts are ongoing in seven regions — Africa, Eastern Europe, the Pacific Rim, Russia and the Newly Independent States, South Asia and the Near East, Western Europe, and the Western Hemisphere. In each region, countries are assisted with adapting their power sectors to meet local demands and environmental pressures. This assistance facilitates dialogue between financial institutions and U.S. companies.

International Capacity Building

To assist in the deployment abroad of U.S. clean coal technologies and advanced power systems, the C&PS Advanced Research program is developing the International Capacity Building initiative. Capacity building allows for technical training, operational skills development, and technical information transfer to impart operational experience and hardware understanding of U.S.-based technologies to international partners. This technology transfer will be accomplished via workshops, seminars, training, on-site visits, and technical exchanges through publications dissemination.

Technology outreach efforts through the International Capacity Building initiative will assist in developing policies and strategic plans for the use of U.S. clean coal technology as a means of furnishing possible solutions to the emerging electrification needs of African, Turkish and Middle Eastern, South American, Eastern European, and Asian communities.

Computational Energy Science

The Focus Area for Computational Energy Science at NETL is developing a set of complex but flexible computation tools that will allow more rapid and efficient scale-up of new subsystems, devices, and components, and will reduce the need for large and expensive demonstration-scale testing of integrated energy systems. The Focus Area will be a significant contributor to the Vision 21 program, and work will be closely integrated with research and development activities sponsored by the Vision 21 program and other related FE programs. The Focus Area will perform three categories of modeling activities:

- Modeling sub-elements in an energy conversion device, such as reactive computational fluid dynamic simulation of a gas turbine combustor. These models will also define the characteristics of materials needed throughout the plant, which will be used to direct the research necessary for their physical development.
- Combining sub-element models to describe initially the steady-state operation, and ultimately the dynamics of a complete energy conversion device.
- Integrating these devices into a model of an overall energy plant.

The computational tasks will allow more rapid and efficient scale-up of new processes, and will reduce the need for large, expensive experimental testing units, thereby reducing operational risks at commercialization. A manufacturing model will be used to aid in commercialization of materials and devices produced from the research by defining the most cost-effective mass production methods. Experiments and tests will be conducted for model validation.

The approach will be to establish an extensive network of interconnected partnerships. NETL will be the nucleus because of its extensive experience and background in advanced processes and simulations, and its implementation role in the FE and C&PS programs. Partnerships with national laboratories, universities, software developers, and energy companies will be organized in several coordinated key technology areas to form the technical backbone of the Focus Area.

A stakeholder group consisting of industry, academia, and government, will be established to provide input to the Focus Area activities.

In Partnership with Industry

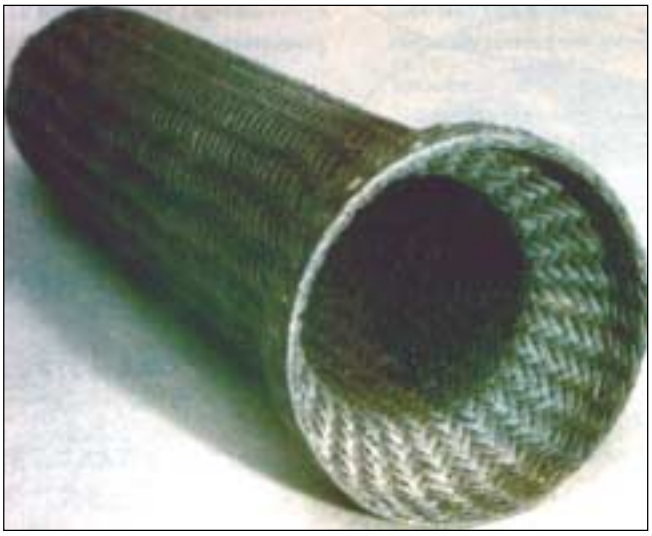
Ceramic Hot-Gas Filter Materials

The difficult issue of removal of particulate matter from hot gas streams in pressurized fluidized-bed combustion (PFBC) and integrated coal gasification combined-cycle (IGCC) systems has been addressed by two developments of the Advanced Research Materials program area. In industry/DOE cost-shared collaborations, the 3M Company and Pall Corporation have, respectively, commercialized ceramic composite and metal alloy filters. The 3M Ceramic Composite Filter is a lightweight ceramic composite filter made of woven Nextel™ fibers coated with silicon carbide, which was produced under license of the DOE-developed technology. 3M has extended and patented its development to an all-oxide filter of similar design.

Pall Corporation's iron aluminide filter is a porous metal filter made of a highly oxidation- and sufidation-resistant aluminide alloy. The application of this alloy as a filter material was explored in the Materials program area and extended to demonstration scale under the hot gas cleanup research.

Both the 3M and Pall filters are being demonstrated at the Power Systems Development Facility in Wilsonville, Alabama, as well as in the numerous installations in Europe and Asia. These are developments of considerable importance, both with respect to enabling technologies for PFBC and IGCC systems, and commercialization. For 300-MWe systems, over 3,000 of these filters would be required for an oxygen-blown IGCC and over 30,000 would be required for a PFBC.

The Bilaspur Coal Washery Project in the state of Madhya Pradesh is India's first private commercial coal washery for electric power generation



A lightweight ceramic hot-gas filter material developed by the Advanced Research Program is now widely used to remove hot gas particulates in fossil-fueled power generation and industrial systems

International

Since 1982, NETL has managed six coal-related projects in India for the U.S. Agency for International Development. The total value of these projects, including contributions from the various Indian parnters, is about $80 million.

One of these projects, the U.S. Asian Environmental Partnership's Indo-U.S. Coal Preparation and Beneficiation Project, supported deployment of an advanced coal-cleaning circuit (based on U.S. technology supported by DOE) at the first commercial non-coking coal washery in India. The objective of this project was to demonstrate production of coal with less than 30 percent ash in the 2.5-million ton/year commercial washery. Two U.S. firms, Spectrum Technologies, and CLI (a U.S. coal preparation design company), have been awarded a $12-million engineer, procure, and construct contract and a $4-million-per-year operation and maintenance contract.